A numerical analysis of the inertial correction to Darcy's law

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Abstract:

Our interest in this work is the stationary one-phase Newtonian flow in a class of homogeneous porous media at large enough flow rates so that the relationship between the filtration velocity and the pressure gradient is no longer linear. The non linear -inertial- correction to Darcy's law is investigated from a numerical point of view on model periodic structures made of regular arrays of cylinders. The starting point of the analysis is the macroscopic model resulting from the volume averaging of the mass and momentum (Navier-Stokes) equations at the pore scale. Identification of the macroscopic properties in this model is made by first solving the microscopic flow as well as the closure problem resulting from the upscaling. From these solutions, the inertial correction is computed and analyzed with respect to the Reynolds number and the pressure gradient orientation relative to the principal axes of the periodic unit cell.

Our results indicate that, in the general case, for ordered structures, the inertial correction to Darcy's law, i) involves a non-symmetric tensor even if the structure is isotropic in the Darcy regime, i.e. is characterized by a spherical permeability tensor. The symmetry exists only when the pressure gradient is applied along a symmetry axis of the unit cell; ii) the correction vector to the Darcy's law is neither aligned with the applied pressure gradient nor with the mean flow: the macroscopic force exerted on the structure is not a pure drag; iii) the onset of the deviation from Darcy's law is characterized by a correction which varies with the mean velocity magnitude to the cube (weak inertia regime); iv) the quadratic correction, classically referred to as the Forchheimer correction, is an approximation which does not hold at all for certain particular orientations of the pressure gradient in this type of structure.